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# Measurements of Mobile Phone Antennas in Small Reverberation Chambers

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**Original scientific paper**

The paper gives a summary of the work that have been performed in the Antenna group at Chalmers University of Technology on measuring antennas for mobile phones in reverberation chambers. Reverberation chambers were originally developed for EMC measurements. We have shown that it also can be used to measure performance of antennas that are designed for use in multipath propagation environment, as well as the performance of complete phones. The antennas and phones can be measured with or without the presence of a head phantom or other objects. The antenna measurements give both radiation efficiency and reflection coefficient at different positions relative to an object such as a head phantom, as they would appear if the antenna and the head phantom were located in free space. The phone measurements give the total radiated power, which we refer to as the telephone communication power (TCP), also at different positions relative to an object. The present summary includes results from both antenna and phone measurements.

**Key words:** mobile phone, antenna, reverberation chamber

## 1 INTRODUCTION

Reverberation chambers for EMC measurements have been reported since 1976. The statistical properties of the chamber were first investigated theoretically in [1]. The quality factor of the resonant modes in the chamber plays an important role, and is affected by wall losses, absorbing objects in the chamber, aperture leakage and the internal antennas [2]. The statistic nature of the measurements is obtained by mechanically stirring the field, and by scanning the measurement frequency, referred to as frequency stirring. The response of an electric dipole inside the chamber is studied theoretically in [3]. The received power averaged over all mechanical stirrer positions and the bandwidth of the frequency stirring is shown to be proportional to the radiation efficiency of the antenna.

The radiation efficiency is a classical antenna performance parameter that has shown to be very convenient in characterizing antennas for mobile and wireless terminals that operate in complex multipath environment. The radiation efficiency can be separated in two factors: the absorption efficiency due to ohmic losses in the antenna and its nearby environment (such as a phantom), and the reflection efficiency due to reflections (mismatch) at the input port of the antenna [4]. We have shown that the radiation efficiency of mobile phone antennas can be measured in reverberation chambers [5]. We have also shown that the multimode environment in a reverberation chamber corresponds to a uniform multipath environment in terms of incident plane waves [6]. We have shown that it is possible to measure radiation efficiency in the GSM 900 MHz band even in a very small reverberation chamber of 1 m size, if we locate the antenna on a rotate able platform, referred to as platform stirring [7]. Then, we have additionally to frequency stir (average) over 25 MHz in order to get reasonable accuracy. The frequency stirring makes the resolution of the radiation efficiency measurement 25 MHz. We have discovered a frequency region with very low mode density (mode hole) in the original 1 m high chamber [6]. To eliminate this problem we increased the height of the chamber to 1.6 m (Figure 1). All the results in this paper except the results in Figure 5 have been measured in the 1.6 m high chamber.

We have developed special techniques in order to remove an erroneous bias of the transfer function of the chamber, and to extract the input reflection coefficient in free space from the statistic reflection coefficient in the chamber [8]. These features are obtained by signal processing of the S-parameters of the chamber (Figure 1 middle).

We have developed a measurement set-up for measuring the total radiated power of mobile phones, conveniently referred to as telephone communication power (TCP). Bluetest AB has measured TCP of 20 phones on a contract for TCO Development AB (www.tco.se). TCO is known for

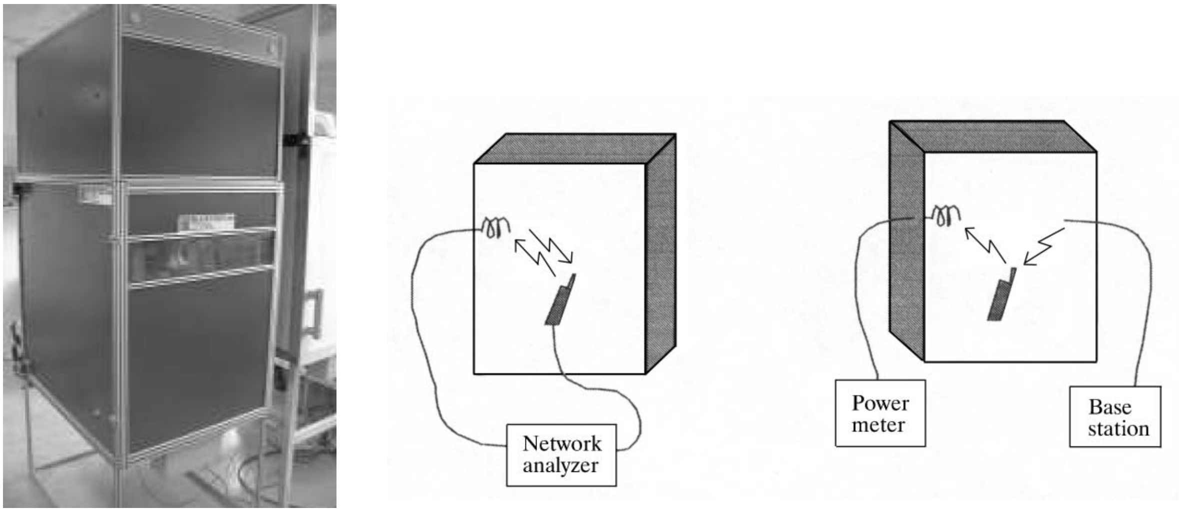



*Fig. 1 Bluetest's 2nd generation reverberation chamber (0.8 m × 1.0 m × 1.6 m), set-up for measuring radiation efficiency and input mismatch of phone antenna, and set-up for measuring telephone communication power (TCP), respectively*

its user specifications of computer screens, and they are now also preparing their own specifications for userfriendly phones.

The methods and chamber are patent applied [9], and the start-up company Bluetest AB (www.bluetest.se) has been formed to commercialize them.

In the presentation associated with this paper we will summarize the applications of the chamber that are described in the above referred papers, the Licentiate thesis [10], the Master theses [11] and [12], and in the project report [10]. We will also present preliminary results of the measurements of the 20 phones for TCO. The present written summary will mainly contain results from [12] and the TCO measurements.

The initial measurements in the reverberation chamber have been verified against measurements in anechoic chambers (reflection coefficient), and against computations of a validation case with a simple geometry, [6, 13] and [14].

## 2 DESCRIPTION OF ANTENNA MEASUREMENTS AND RESULTS

The two measurement set-ups are illustrated in Figure 1. The instruments and the five step motors of the chamber are controlled from a PC (not shown), which also gathers all results and processes them. The first set-up is for antenna measurements. We measure the S-parameters between the ports of the excitation antenna (EA) and the antenna under

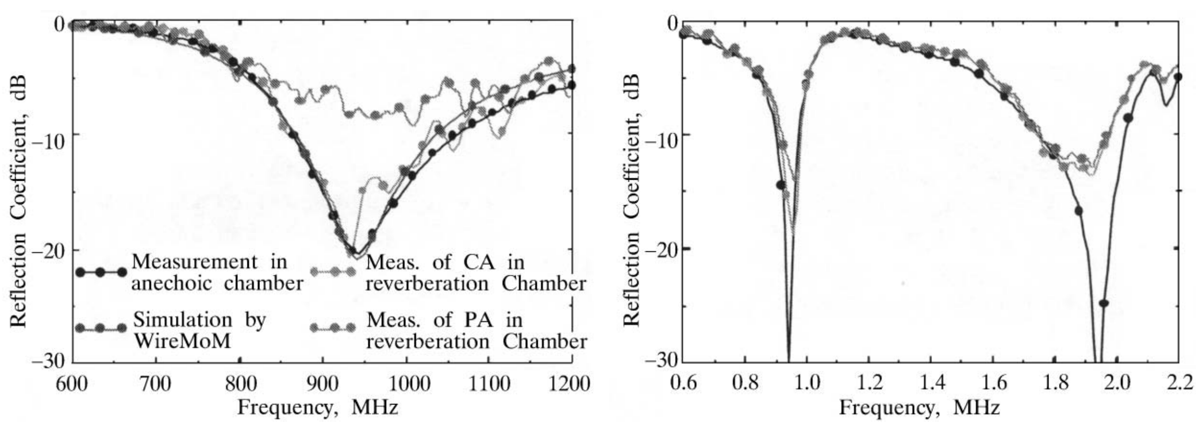



*Fig. 2 Reflection coefficient at input port of dipole antenna (left) and of short external antenna on mobile phone (right). The antennas are located far away from the head phantom. The different curves show results in anechoic chamber (i.e. free space), results of simulations (left figure only), results based on power averaging (PA) of S22 in Bluetest's reverberation chamber, and results based on averaging the complex amplitude of S22 in Bluetest's chamber. The latter is very similar to the free space values [8]*

test (AUT). From these we can extract an erroneous bias due to direct coupling between the two antennas, or due to a dominating mode in the chamber. We can also extract the reflection coefficient as it appears at the input port of the AUT if it was located in free space. We need a good reference level for the radiation efficiency. This is obtained by correcting the transfer function S12 of the chamber for the mismatch of the EA and AUT. Thereby, the corrected $/S12/^2$ varies smoothly with frequency $f$, following closely a $1/f^2$ curve. This is then averaged with $1/f^2$ frequency weight over a large bandwidth in order to obtain a very accurate reference level. The corrected $/S12/^2$ level of the AUT is averaged over 25 MHz in the GSM 900 MHz band and 75 MHz in the GSM 1800 MHz band, in order to improve accuracy. The absorption efficiency becomes the difference between the corrected $/S12/^2$ levels of the AUT and of a lossless reference antenna. We get the total radiation efficiency by including the mismatch part again. The measurement procedures are described in more detail in [11].

Some measured reflection coefficients are shown in Figure 2. We see that the case called CA follows quite closely the measured result in an anechoic chamber. The CA curve is obtained by complex amplitude averaging (CA) of the S22 of the AUT. The CA removes effectively the statistic part of S22, so that we are left with the deterministic free space value. We see that if we use power averaging instead, in the same way that we do in order to get the radiation efficiency from S12, the level is too high. It is actually the sum of the power reflection coefficient of the AUT and the average reflected power level in the chamber. The latter is about −9 dB in this case, as the chamber is loaded with a lossy object. An actual phone antenna has also been measured (right graph). Then, the reflected level due to the chamber is lower because the radiation efficiency of this antenna is much lower than that of the halfwave dipole in the left graph. The chamber level when measuring S22 is reduced by twice the radiation efficiency.

We have also measured the radiation efficiency of different phone antennas in the different free space, cheek and tilt positions specified by the CENELEC standard for SAR (Specific Absorption Rate) measurements. We have also manufactured a hand phantom (see Figure 3) and filled it with the same liquid that we use for the head phantom for the GSM 900 MHz measurements. This is the alcohol based liquid recommended in the latest CENELEC standard. The average of the complex permittivity of muscles and bones are close to that of grey brain cells, so for the purpose of our tests it is satisfactory. The phones with hand are also measured in the different free space, cheek and tilt positions (Figure 3). We have used three phones, one with an external antenna and another with a built-in antenna (Figure 4). The external antenna is extractable (not the original antenna following the phone), and has been measured both in its short and extracted positions. A lot of results are available in [12]. Here we only show as an example the results in Figure 4. They are explained in the figure text. We see the following trends. The radiation efficiency is highest for the extracted antenna, and it is most narrowband for the built-in antenna. The effects of the head are much smaller in the 1800 MHz band than at 900 MHz. The frequency variation of the radiation efficiency is much smaller in the upper band than in the lower. The results in Figure 4 are without the hand phantom. The results with hand phantom show that the performance of the extracted antenna is very little influenced by the hand. The radiation efficiency of the built-in antenna is reduced by about 2 dB due to the hand, and the performance of the short external antenna by less than 1 dB.

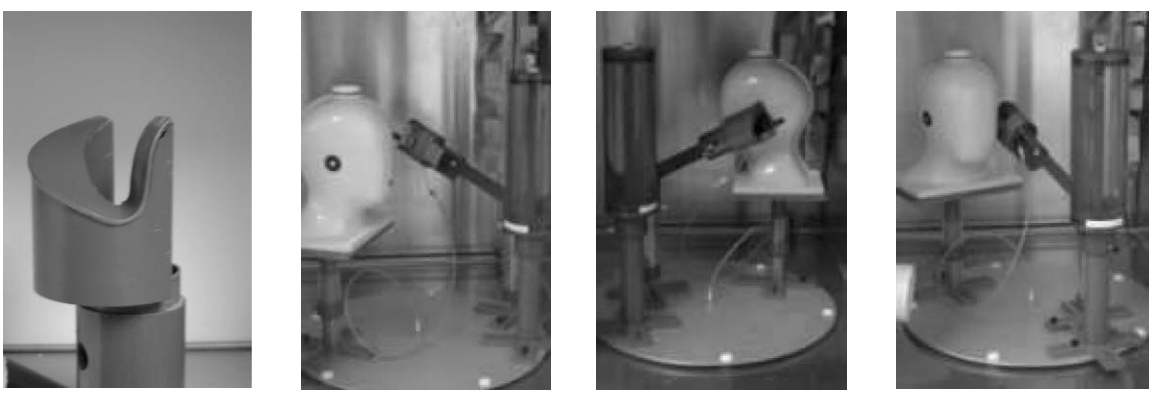


*Fig. 3 Photos of left hand phantom, and measurement set-up inside chamber for free space, cheek and tilted positions, respectively, all with hand*

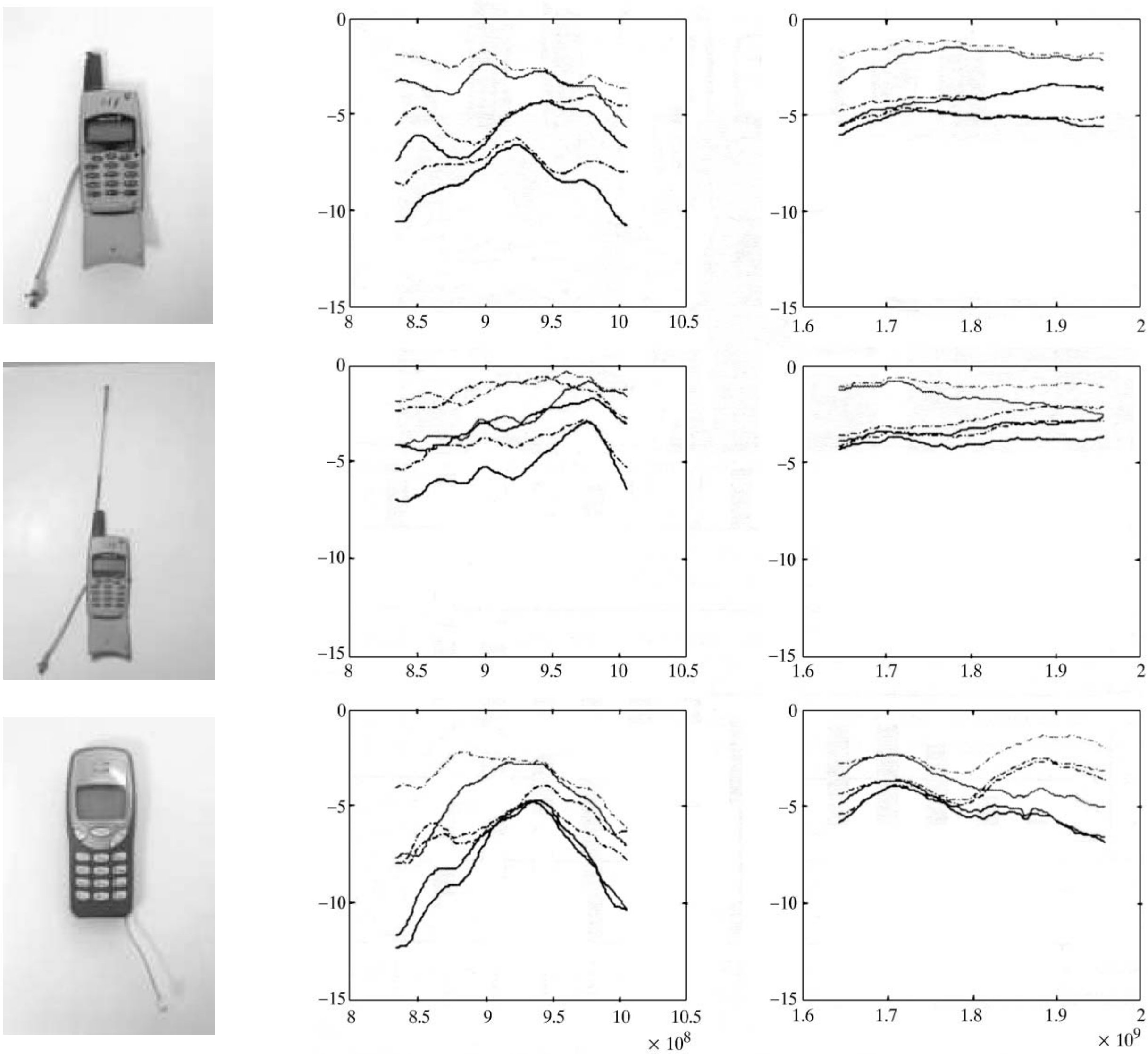
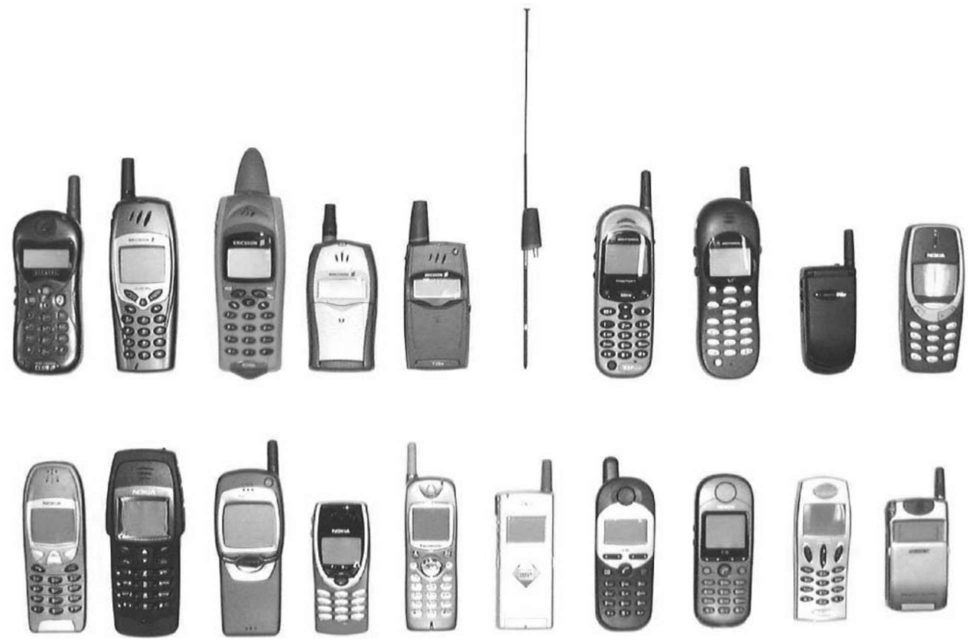



*Fig. 4 Radiation efficiency in dB versus frequency in Hertz in GSM 900 (middle) and GSM 1800 (right) bands. In all cases the phones are located on the left side of the head phantom. The two upper graphs are for a phone with an external extractable antenna, when the antenna is not extracted (short external case). The two middle graphs are for the same phone when the antenna is extracted. The lower two curves are for a phone with a built-in antenna. The photos show a short cable coming out from each phone. This is attached to the antenna port inside the phone. The loss of this cable is included in the shown efficiency values. There are several curves in each graph. The dashed curves are the absorption efficiencies, whereas the solid curves are the total radiation efficiencies included also mismatch losses. The green curves (look light gray when printed in gray scale) are the efficiencies in free space position. The red curves (look dark gray when printed) are the efficiencies in the cheek position. The blue curves (look black when printed) are the efficiencies in the tilted position*

## 3 DESCRIPTION OF TCP MEASUREMENTS AND RESULTS

The set-up for measuring telephone communication power (TCP) is shown in Figure 1 to the right. The TCP is the same as the total radiated power leaving a sphere around the phone (and the phantom if this is used). We use a base station simulator to control the output power level of the phone and its frequency. The phone is controlled to transmit successively at five frequencies within the 890 – 915 MHz GSM transmit band. We measure the received power at the EA at all these five frequencies and calculate the average power. This corresponds to 25 MHz frequency stirring.

Bluetest AB has measured TCP of 20 phones on a contract for TCO Development AB (www.tco.se). TCO is known for its user specifications of computer screens, and they are now also preparing their



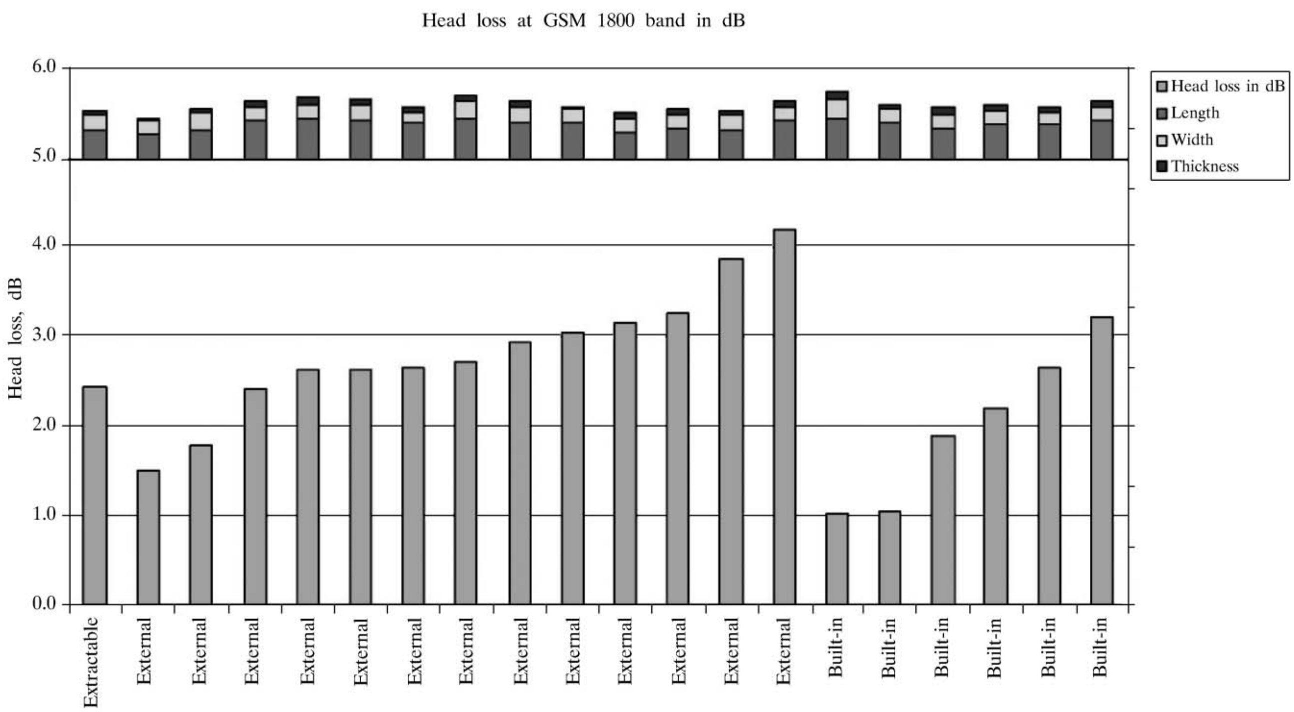



*Fig. 5 Photo of the 20 phones that have been measured for TCO in the Bluetest reverberation chamber. The measurements set-up is for measuring telephone communication power (TCP), with and head phantom with the phones in different positions. The lower figure shows the maximum head losses in dB in the GSM 1800 MHz band. The maximum head loss is the difference between the TCP in dBm in free space and the lowest TCP in dBm of the four phone positions (right and left cheek, right and left tilted, right). We can at present not publish the phone manufacturers, so we have instead sorted the phones according to antenna type and size of head loss. Note that the head loss is caused both by absorption and mismatch. The head losses in the GSM 900 MHz band are typically between 5 and 9 dB, and between 1.5 and 4.5 dB in the GSM 1800 MHz band as shown in the figure. The upper symbols in the graph illustrate the size of the phone. The height of the lower part of the symbol is proportional to the length of the phone, the medium part to the width of the phone, and the upper part to the thickness of it*

own specifications for user-friendly phones. The specifications include both SAR and TCP. The 20 phones are shown in Figure 5 together with the head loss. The results are explained in the figure text. The complete set of results with TCP values in Watts and dBm will be available at a later time.

## 4 CONCLUSION

We have shown results that demonstrate that the Bluetest reverberation chamber can be used for measuring radiation efficiency, absorption efficiency and input reflection coefficients, as well as total radiated power of mobile phones. These measurements can be done with a head phantom or other objects present in the vicinity of the phone. We have also studied the relation between the absorption efficiency and SAR values published elsewhere. This shows that for a given phone and antenna, the SAR is reduced if the absorption efficiency can be increased.

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**Mjerenje antena pokretnih telefona u malim ječnim komorama.** Rad prikazuje rezultate istraživanja provedenih na Chalmers University of Technology o mjerenjima antena za pokretne telefone u malim ječnim komorama. Ječne su komore razvijene ponajprije za mjerenja na području elektromagnetske kompatibilnosti. Pokazali smo da se ječne komore mogu koristiti i za mjerenje osobina antena koje su predviđene za rad u uvjetima višestaznog rasprostiranja kao i za mjerenja osobina cjelokupnih pokretnih telefonskih uređaja. Antene i telefoni mogu se ispitivati sa ili bez prisutnosti fantoma ljudske glave ili drugih objekata. Mjerenjem se za antene može odrediti djelotvornost zračenja i koeficijent refleksije za različite položaje antena u odnosu na vanjske objekte kao što je npr. fantom ljudske glave. Rezultati mjerenja su jednaki kao u slučaju kad se antena i fantom nalaze u slobodnom prostoru. Mjerenjima na cjelokupnom pokretnom telefonu određuje se ukupna zračena snaga, koju nazivamo komunikacijska snaga telefona. Ova se snaga također određuje za različite položaje telefona u odnosu na vanjske objekte. U radu su prikazani rezultati mjerenja na antenama i telefonima.

**Ključne riječi:** pokretni telefon, antena, ječna komora

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